In the formal geometrical theory, we shall take into account only those orientations of each crystal form that may reasonably be expected under natural conditions to lead to sufficient concentration of light for the production of readily observable effects: that is, only orientations that (1) correspond to the minimum minimorum, or (2) predominate as a result of a restrictive influence that deprives the crystal of one of its degrees of freedom and at the same time correspond to minimum deviation, or (3) predominate because of a restrictive influence that deprives the crystal of two of its degrees of freedom, in which case all deviations must be considered. In general, only reflections that are total need be taken into account.

The different orientations that are to be taken into account in any case, for deriving the collective effect of all the crystals, may be conveniently specified by the positions in which the principal crystallographic axis may lie in space, and the extent to which rotation of the crystal may take place around the axis.

THE OPTICAL METEORS PRODUCED BY CRYSTALS ORIENTED AT RANDOM

The case in which the crystals have three degrees of freedom and are oriented completely at random—as many crystals lying with their axes in one position as in any other, and rotating freely around their axes—is easily disposed of. The only important relative concentration of light into a limited region of the sky is produced by refraction at and very near the minimum minimorum.

Any plane through the line from observer to luminary will intersect some of the crystals; a certain proportion of these crystals will happen to be so oriented that the section by the plane is a principal plane of some one of the refracting angles, or very nearly so. All rays in this plane that are incident on such crystals will be refracted in or near a principal plane; the sections themselves will be randomly oriented in the intersecting plane, so that all possible values of the angle of incidence, and hence of the deviation, will occur. Of the crystals that produce any given deviation D, all those on a line through the observer at an angle D with the line from observer to luminary will send the refracted ray to the observer; the observer will therefore see an image on the sky at an angular distance from the luminary equal to the deviation, and in a direction from the luminary on the great circle where the intersecting plane cuts the celestial sphere. The images corresponding to the different deviations in any such plane will collectively form an arc extending along this great circle from the minimum minimorum to the maximum deviation, but fading rapidly in brightness with increasing deviation. The same effect will be produced in all planes through the line from observer to luminary, all of which may be obtained by revolving a plane around this line; hence a circular ring of light will appear, centered at the luminary, with a sharp inner edge (contrasting with a comparatively dark sky within) of radius equal to the minimum minimorum, and a diffuse outer border merging into a general sky glare beyond.

The concentration of light near minimum deviation in the principal plane is so strong that these circular halos may be distinguishable even when particular orientations predominate among the crystals sufficiently to give other arcs also.

Each refracting angle can produce such a circular halo; and it is to phenomena of this type that the generic name halo properly applies (Gr., ἅλως). The radii of all these halos that can be produced by the crystal forms we have enumerated are as follows:

Refraction angle		Radius of halo		Crystal elements required
°	′	°	′	
24	51	7	54	Hexagonal prism with pyramid.
49	42	17	06	Pyramid.
53	58	18	58	Bipyramid.
60	00	21	50	Hexagonal prism.
63	01	23	24	Hexagonal prism with pyramid.
65	09	24	34	Pyramid with plane base; or bipyramid with one truncation.
76	24	31	49	Pyramid.
90	00	45	44	Hexagonal prism, with plane base or truncated pyramid.

The 22° halo is by far the commonest of all halo phenomena; nearly all the others in this table have been observed with certainty, though most of them are very rare.[3]

[3] See W. J. Humphreys, *Physics of the Air*, 3 ed., pp. 534–536, 1940, and the further references there given. *Cf.* Besson, MONTHLY WEATHER REVIEW, 42: 443, 1914, and 51: 254, 1923.

RECALIBRATION OF INSTRUMENTAL EQUIPMENT AT SOLAR RADIO STATIONS

By IRVING F. HAND and HELEN F. CULLINANE

[U. S. Weather Bureau Solar Radiation Supervisory Station, Blue Hill Observatory of Harvard University, Milton, Mass., October 1941]

The desirability of recalibrating the equipment used at stations where records of solar radiation are now being made has long been recognized. The original calibrations of the pyrheliometers were made by three separate agencies: (1) the Solar Radiation Investigations section of the United States Weather Bureau (2) the Eppley Laboratory, and (3) the National Bureau of Standards. Calibrations by (1) were made by occulting the sun at regular intervals on clear days, subtracting the values of the sky radiation thus determined from the total radiation on a horizontal surface, and obtaining the ratio between this result and the otherwise measured value of the normal incidence radiation reduced to a horizontal surface by means of the sine law. Calibrations by (2) and (3) were obtained by direct comparison against standards furnished by the Weather Bureau. It was obvious that great improvement would be obtained if all instruments were recalibrated against a single carefully standardized pair of pyrheliometers; and the need for this increased after a more thorough study of the Eppley pyrheliometer had shown that the cosine law failed to hold with low sun.[1] Moreover, some stations had not been inspected for over 10 years, and it was thought best to check not only the pyrheliometers but also the recording equipment and other accessories.

Between March and July 1941, all stations listed in table 1 were therefore visited; the pyrheliometers were carefully leveled, where necessary, and checked against either the 10- or the 50-junction standards, which previously had been standardized directly against the standard Smithsonian silver-disk normal incidence pyrheliometer. We may now be confident that all these stations are on the same standard, and as close to the Smithsonian scale of pyrheliometry as we are able to place it. Table 1 gives the average monthly e. m. f. of all pyrheliometers checked, and also the percentage change from the mean

[1] Byron H. Woertz and Irving F. Hand. The Characteristics of the Eppley Pyrheliometer. MONTHLY WEATHER REVIEW, 69: 146–148, 1941, May.

factor formerly used. The new monthly values of e. m. f. were calculated by the formula given by Woertz and Hand,[1] but this formula was somewhat modified to take account of the fact that the variation in e. m. f. applies only when the sun is shining.

On the whole, the pyrheliometers themselves were in fairly good condition and showed less change than we had anticipated; the Madison standardization showed no appreciable change, while New Orleans had a 6.5-percent drop.

Some changes were noted in the full-scale deflections of the microammeters, and calculations made to rectify the reductions. The integrated effects of the total changes are shown in table 2, thus enabling previously published data to be brought up to date if desired.

Table 1 also lists the percentage changes in the reduction factors necessary to reduce the integrated areas to values in gram calories. It will be noted that on the whole the algebraic sign is reversed from the values appearing for the percentage change in e. m. f. because, for example, if the pyrheliometer has been found to be less efficient, naturally a larger factor will be necessary. It also will be noted that while the values for the stations utilizing potentiometers remain unchanged except for change in sign, the stations using microammeters show considerable change in values. All the potentiometers checked were adjusted so as to give their rated full-scale deflection; but this is impracticable in the case of microammeters, and it was therefore necessary to accept the current values of these latter instruments. Unfortunately, too, it has been found that microammeters have a greater tendency to vary in full-scale deflection than do potentiometers; and because of this fact, and also because the errors arising from free-air temperature changes are reduced to a minimum through the use of the null potentiometric method, the Weather Bureau is replacing microammeters with potentiometers as rapidly as funds permit.

The reduction factors for New York City showed the greatest change, 10.3 percent, whereas the standardization of the pyrheliometer gave a value only 2.4 percent higher than that formerly obtained. The remaining 7.9 percent change was owing to shift in the full-scale deflection of the recording microammeter.

The change in the equipment at Madison, Wis., was all but inappreciable, being less than one-tenth of 1 percent.

Normals for all stations where the apparatus has recently been checked were recomputed, and placed on the new standard. The values in the last row of table 1 may be used by those who desire to bring previously published data up to date. Table 2 gives complete instrumental data for the stations.

[1] Byron H. Woertz and Irving F. Hand. The Characteristics of the Eppley Pyrheliometer. MONTHLY WEATHER REVIEW, 69: 146–148, 1941, May.

TABLE 1.—New pyrheliometric standardizations [1] (Mv/gm cal/cm²)

	Albuquerque, N. Mex.		American University		Blue Hill, Mass.		Riverside, N. Y.		Chicago, Ill.		Twin Falls, Idaho		New Orleans, La.	
	New	Old	New	Old	New	Old	New	Old	New	Old	New	Old	New	Old
January	8.732		1.904		1.670		1.390		8.480		8.981		8.062	
February	8.753		1.905		1.675		1.391		8.509		9.008		8.066	
March	8.772		1.906		1.683		1.397		8.530		9.032		8.085	
April	8.806		1.912		1.688		1.400		8.539		9.070		8.099	
May	8.826		1.913		1.692		1.401		8.546		9.082		8.102	
June	8.835		1.916		1.693		1.403		8.553		9.084		8.101	
July	8.845		1.914		1.692		1.402		8.546		9.082		8.103	
August	8.826		1.912		1.690		1.402		8.543		9.075		8.100	
September	8.810		1.909		1.686		1.394		8.524		9.048		8.089	
October	8.760		1.901		1.677		1.394		8.508		9.014		8.077	
November	8.722		1.896		1.672		1.389		8.500		8.985		8.058	
December	8.702		1.892		1.671		1.389		8.500		8.993		8.051	
Mean	8.782	9.12	1.907	1.81	1.682	1.67	1.396	1.43	8.523	8.79	9.038	9.18	8.083	8.61
Percentage change from old e. m. f.	−3.8		+5.4		+.7		−2.4		−3.1		−1.6		−6.5	
Percentage change in reduction factors	+.7		−5.4		−.7		+3.4		+3.3		+ .5		+6.5	

	La Jolla, Calif.		Fresno, Calif.		Lincoln, Nebr.		Madison, Wis.		New York		State College		Cambridge, Mass.	
	New	Old	New	Old	New	Old	New	Old	New	Old	New	Old	New	Old
January	7.576		7.160		1.386		1.874		5.584		0.521		8.370	
February	7.595		7.120		1.395		1.876		5.596		.510		8.202	
March	7.622		7.203		1.399		1.880		5.629		.509		8.185	
April	7.646		7.218		1.401		1.884		5.641		.501		8.068	
May	7.656		7.227		1.403		1.887		5.653		.501		7.995	
June	7.660		7.230		1.404		1.889		5.658		.500		8.036	
July	7.656		7.224		1.403		1.888		5.657		.500		8.034	
August	7.653		7.215		1.402		1.884		5.649		.501		8.065	
September	7.630		7.206		1.398		1.880		5.632		.504		8.094	
October	7.606		7.174		1.394		1.877		5.614		.506		8.140	
November	7.572		7.154		1.389		1.875		5.590		.518		8.318	
December	7.554		7.152		1.388		1.874		5.580		522	[1]	8.396	
Mean	7.619	8.37	7.190	7.02	1.397	1.37	1.881	1.88	5.624	5.49	5.08		8.159	8.516
Percentage change from old e. m. f.	−10.0		+2.4		+2.0		0		+2.4				−4.4	
Percentage change in reduction factors	+1.2		−1.9		−2.9		0		−10.3				+4.4	

[1] New station.

TABLE 2.—*Instrumental data*

Station	Under direction of—	Eppley pyrheliometer number	E. m. f. per gram-calorie, mv.	Resistance, ohms	Registers	Resistance, ohms	Full-scale deflection	Notes
1. Fairbanks, Alaska	U. S. Weather Bureau	235	7.46	84.8	Engelhard	151	30 ma	Number unknown. (C. I. C.)
2. Lincoln, Nebr.	do	296	1.386–1.404	32.0	Leeds & Northrup		4 mv	Normal incidence also. (C. I. C.)
3. Madison, Wis.	do	359	1.874–1.889	36.0	do		4 mv	Do.
4. New York, N. Y.	do	191	5.580–5.658	84.2	Engelhard, 30749	137	27.8 ma	Register needs replacing. (C. I. C.)
5. Washington, D. C.	U. S. Weather Bureau, American University.	447	1.892–1.916	37.0	Bristol, model 527, serial 567. Engelhard, 27346		4 mv	Dr. E. W. Engel.
6. Albuquerque, N. Mex.	U. S. Weather Bureau, airport.	316	8.702–8.845	113.0		132	28.6 ma	Engelhard soon to be replaced with potentiometer.
6a. Albuquerque, N. Mex.	do	656	1.429		Leeds & Northrup			(Should be installed by end of 1941.)
7. Fresno, Calif.	U. S. Weather Bureau	223	7.160–.7230	82.8	Engelhard, 26209	134.3	30.8	Excellent station.
8. Chicago, Ill.	do	358	8.480	111.0	Engelhard, 27273	139.5	50.4	Engelhard needs replacing.
9. Bismarck, N. Dak.	do							Station to be opened shortly.
10. Nashville, Tenn.	do							Do.
11. Miami, Fla.	do							Do.
12. San Juan, P. R.	U. S. Weather Bureau, Puerto Rico.	445	1.90	36.0	Modified potentiometer			Dr. G. W. Kenrick.
13. Ithaca, N. Y.	Cornell University	295	1.813	30.0	Leeds & Northrup			Dr. A. J. Heinicke, department of pomology.
14. Riverside, Calif.	University of California	301	1.389–1.403	34.0	Engelhard, 30749	172	14.7 ma	Dr. E. R. Parker, citrus station.
15. Twin Falls, Idaho	U. S. Bureau of Plant Industry.	386	8.981–9.084	111.0	25166	129.7	28.9 ma	Station in very poor shape—should have new instruments.
16. Blue Hill, Mass.	Harvard	498	1.670–1.693		Leeds & Northrup, 251588		2.8 mv	Alternate recorders now and then. Dr. Charles F. Brooks.
17. State College, Pa.	State College	(?)	0.662	(?)	Leeds & Northrup circular sheets.			Dr. H. Landsberg. Pyrheliometer has had new cover; very inefficient outfit.
18. New Orleans, La.	Tulane University	(?)	8.051–8.103	(?)	Leeds & Northrup, 80 div., ½ hour lines.		16.0 mv	Dr. Henry Laurens.
19. La Jolla, Calif.	Scripps Institute of Oceanography, University of California.	335	7.554–7.656		Englehard		30.8 ma	Dr. George F. McEwen.
20. Torrey Pines, Calif.	U. S. Bureau of Plant Industry.	518	8.035–8.112		Leeds & Northrup		16. mv	Dr. L. A. Richards.
21. Indio, Calif.	do	519	7.903–7.968		do		16 mv	Dr. L. A. Richards or Dr. Aldrich.
22. Washington, D. C.	National Bureau of Standards.	387	8.36		do		(?)	Pyrheliometers need restandardizing. 50-junction.
23. Washington, D. C.	do	393	1.88		do		(?)	10-junction.
24. Friday Harbor, Wash.	University of Washington, Seattle, Wash.	262	8.71		Engelhard			Dr. C. L. Utterback. Suggested that they have their pyrheliometer leveled. No reply.
25. Newport, R. I.	Eppley Laboratory	362 489 389 391	1.589 1.382 7.685 7.960		Various potentiometers			Mr. Roy Anderson, Manager, or Mr. William R. Gray.
26. Cambridge, Mass.	Massachusetts Institute of Technology.	434	8.52		Leeds & Northrup			Dr. Hoyt C. Hottel.

TROPICAL DISTURBANCES OF SEPTEMBER 1941

By HOWARD C. SUMNER

[Weather Bureau, Washington, October 1941]

The first tropical disturbance of the 1941 hurricane season appeared in the northern Gulf of Mexico on the evening of September 11. This is the first time in over 25 years that the North Atlantic area has been free from tropical disturbances until so late in the season. Annual records, from 1887 to the present time, show that only on two other occasions have tropical storms failed to develop before the 11th of September. In 1907 and 1914 the first tropical disturbances of the season were observed on September 16 and September 14, respectively.

After the unusually late start, four disturbances developed in rapid succession, between September 11 and 23, two of which were accompanied by winds of full hurricane force. The last three of these disturbances were in progress at the same time, with advisories being issued simultaneously by the supervising centers at Washington, New Orleans, and San Juan.

September 11–15, 1941.—A Gulf disturbance of slight intensity appeared on the morning of September 11, and was centered at 7 a. m.[1] about 120 miles southeast of Port Eads, La. The center moved very slowly in a west-northwesterly direction toward the north Texas coast and moved inland, between Galveston and Port Arthur, the night of September 14–15, resulting in a series of squalls at Port Arthur.

The lowest barometer reported during the short 5-day course of this storm, 1,002.7 millibars (29.61 inches), accompanied by a force 8 wind (Beaufort scale), came from a ship near 28°06′ N., 90°18′ W., on September 13.

On the coast the highest wind velocity registered was 31 miles per hour from the east at Port Arthur and the lowest barometer 1,007.5 millibars (29.75 inches) at 4:30 p. m. (C. S. T.) on the 14th at the same station. Rainfall for the 2-day period (14–15) at Port Arthur was 1.52 inches.

This disturbance was sufficiently threatening on the 13th for warnings to be issued to people in low-lying areas; but during the last 24 hours before it crossed the coast it decreased greatly in intensity and no property damage or injuries were reported.

September 18–26.—This hurricane was first noted as a disturbance of slight intensity about 180 miles south of Port Eads, La., on September 18. For 48 hours the center drifted gradually southward toward the Yucatan coast with winds increasing to gale force. During the night of September 20–21 the storm turned, and moving northward retraced its path until, on the evening observation of the 21st, it was again near the region where first detected. It then took a northwestward course through the western Gulf of Mexico and moved inland on the Texas coast near Matagorda at 3:25 p. m. (C. S. T.) on September 23.

A ship near 27°06′ N., 93°42′ W., on September 22 reported a northeast wind, force 12, and a low barometer reading of 985.8 millibars (29.11 inches).

On the coast, Texas City reported the highest recorded

[1] Times mentioned are E. S. T. unless otherwise indicated.